Late Oligocene Through Pleistocene Molluscan Faunas in the Gulf of Alaska Region

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(2 Text figures)

INTRODUCTION

A NUMBER OF GULF OF ALASKA Tertiary formations contain fossil faunas of major importance to studies of North Pacific molluscan biostratigraphy and paleobiogeography (Figure 1). These faunas are, however, very poorly known. The interpretations offered here are based on faunal lists for each formation, but available space prohibits their inclusion in this paper. It is my purpose to give a review of 9 Gulf of Alaska stratigraphic units and their molluscan faunas.

I have treated these stratigraphic units and their faunas under "western Gulf of Alaska" and "northeastern Gulf of Alaska" headings because of significant differences in the faunas and geologic history of these two areas during Neogene time. The discussion deals primarily with the Neogene units of the Gulf of Alaska region, although two units, the Sitkinak Island Narrow Cape Formation, and the Poul Creek Formation, range down into the Paleogene. Quaternary marine deposits are also considered.

These North Pacific molluscan faunas are substantially different from those of the European stratotypes, a factor which makes epoch assignments difficult.

I have attempted to correlate the Gulf of Alaska stratigraphic units with the provincial molluscan chronology of the Pacific Northwest Molluscan Province (ARMENTROUT, 1975; ADDICOTT, 1976), or with the late Pliocene to early Pleistocene marine transgressions of Beringia (HOPKINS, 1967). The Pacific Northwest molluscan stages have been correlated with the benthic foraminifer stages of California, which have in turn been loosely correlated with the modern planktonic foraminifer zones by BERGGREN & VAN COUVERING (1974). By this attenuated series of correlations I have attempted to recognize epoch boundaries in the Gulf of Alaska region. I expect substantial refinement of these correlations to result from future studies of western North American Cenozoic strata. Future research should permit definition of provincial molluscan stages for the Gulf of Alaska region, but present knowledge is insufficient for this purpose, even though a provincial chronology is needed.

In the section that follows, I have given an abbreviated discussion of each Gulf of Alaska stratigraphic unit of late Paleogene to Recent age that bears a significant molluscan fauna. Not all Paleogene or Neogene formations of the area have been discussed. I have attempted to date each unit discussed, and have also offered inferences on water depths and sea temperatures as well as comments on the biogeographic affinities or faunal compositions for the mollusks. My use of European series/epoch terms is in the sense of BERGGREN & VAN COUVERING (1974).

WESTERN GULF OF ALASKA STRATIGRAPHIC UNITS

The Narrow Cape Formation of Sitkinak Island:

Approximately 210 meters of marine fossiliferous siltstone crop out at the axis of a syncline located at the southernmost tip of Sitkinak Island, Alaska. These strata, which were referred to the Narrow Cape Formation by MOORE (1969), conformably overlie the coal-bearing terrestrial Sitkinak Formation of MOORE (1969). Sitkinak Island Narrow Cape Formation strata may be given a new formational name in the future because they differ from the type Narrow Cape Formation strata of Kodiak Island in being gradationally conformable upon the underlying Sitkinak Formation, and in being older, as well as in lacking outcrop continuity. Moore (personal communication, 1976), however, believes that these beds may represent the beginning of the same marine transgression that is represented at Narrow Cape on Kodiak Island, and that the two stratal se-

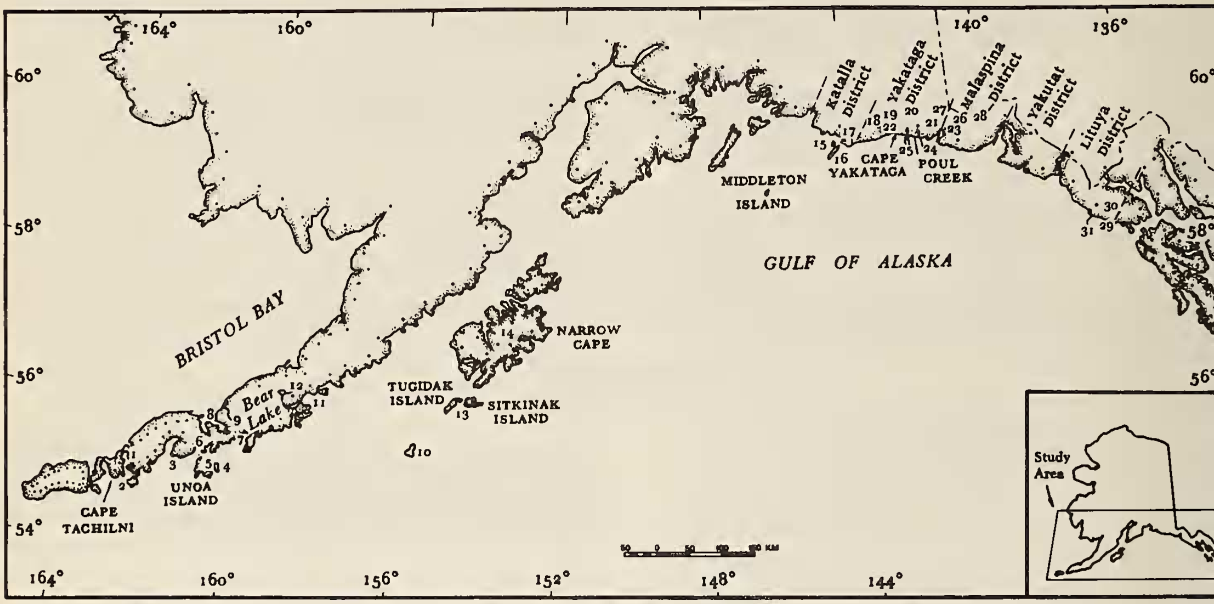

Figure 1

Index Map of the Gulf of Alaska Region Showing Locations of Major Mollusk-Bearing Stratigraphic Units and the Geographic Locations of Places Referred to in the Text

1. Cold Bay
2. Thinpoint Cove
3. Coal Bay
4. Popof Island
5. Zachary Bay
6. Cape Aliaksin
7. Stepovak Bay
8. Port Moller
9. Milky River
10. Chirikof Island
11. Chignik Bay
12. Black Peak
13. Trinity Islands
14. Kodiak Island
15. Wingham Island
16. Kayak Island
17. Suckling Hills
18. Grindle Hills
19. Kosakuts River
20. Robinson Mountains
21. Guyot Glacier
22. Kulthieth Mountain
23. Chaix Hills
24. Munday Peak
25. Yakataga Glacier
26. Samovar Hills
27. Karr Hills
28. Pinnacle Hills
29. Icy Point
30. La Perouse Glacier
31. Topsy Creek

quences should therefore be referred to the same formational unit. Perhaps future knowledge of the offshore subsurface stratigraphy will clarify this point.

To date, no faunal list has been published for the marine strata which crop out along the south coast of Sitkinak Island, but they contain a molluscan fauna now known from collections made by George Moore of the U.S. Geological Survey and by John Armentrout of Mobil Oil Company. This fauna, which consists of about 55 taxa, is not as diverse as that of the type Narrow Cape Formation of Kodiak Island.

The Sitkinak marine strata belong to the Juanian Stage (Addicott, 1976) [=*Echinophoria apta* zone of Durham, 1944] of the provincial molluscan chronology (MacNeil, 1965: 69). Assignment of these strata to the *Echinophoria apta* zone is confirmed by the presence of the zonal index fossil, *E. apta*. The *E. apta* zone corresponds to the upper Zemorrian benthic foraminiferal Stage (Durham, 1944; Armentrout, 1975; Addicott, 1976). Several taxa which indicate that the Sitkinak marine strata are no older than the Juanian or *E. apta* zone are: *Macoma calcarea* (Gmelin), *Macoma incongrua* (von Martens) of Kanno (1971), *Pitar angustifrons* (Conrad), *Spisula albaria* (Conrad), subsp.?, *Spisula* cf. *S. hannibali* (Clark & Arnold), *Natica clausa* (Broderip & Sowerby), and *Polinices* cf. *P. galianoi* Dall.

Taxa not known to occur in strata younger than those of the *E. apta* zone also occur in the Sitkinak marine strata. These taxa are: *Spisula* cf. *S. hannibali*, *Bruclarkia* cf. *B. andersoni* (Wiedey), *Polinices ramonensis* (Clark), and *Priscofusus* aff. *P. stewarti* (Tegland).

Berggren & Van Couvering (1974) suggest that the late Zemorrian is approximately equivalent to planktonic foraminifer zones N2/P21 through N4. If so, the Oligocene-

Miocene boundary may fall high within the *Echinophoria apta* zone, more or less equivalent to the usage of West Coast benthic foraminifer workers. The early Miocene Pillarian molluscan Stage (early Saucesian benthic foraminifer Stage) (Figure 2) is unrepresented in the known surface exposures of the western Gulf of Alaska.

A few diagnostic taxa suggest that the Sitkinak Island Narrow Cape Formation strata were deposited in water no shallower than 18 m, and possibly no shallower than 37 m, and probably no deeper than 186 m or possibly no deeper than about 141 m. Kristin McDougall, of the U.S. Geological Survey (personal communication, Sept. 1976) reports the benthic foraminifers from this section to indicate probable depths between 100 and 300 m. Taken together, the evidence suggests water depths during deposition were primarily in the outer neritic depth zone between 100 and 186 m.

Water temperature during deposition of the late Oligocene Sitkinak Island Narrow Cape Formation was clearly temperate and cooler than that of the Miocene Narrow Cape Formation of Kodiak Island. Whether the water temperature was cool temperate like the present Aleutian-Gulf of Alaska region (Hall, 1964), or mild temperate like the present Oregonian province, is more difficult to assess. Both warmer and cooler faunal elements are present. In general, it seems probable that water temperature was slightly warmer than present water temperature at Sitkinak Island, perhaps somewhat like that near the present cool temperate-mild temperate boundary.

The fauna of the Sitkinak Island Narrow Cape Formation contrasts strongly with that of the Narrow Cape Formation of Kodiak Island. The presence of large *Dosinia, Securella, Anadara (Anadara)*, large fulgorarids, and *Ficus* at Narrow Cape indicates substantially warmer water conditions, probably like those of the present warm temperate province.

The Sitkinak Island Narrow Cape Formation mollusks are divided among stocks that had their principal centers of distribution, or regions of origin, along the Asiatic coast, along the Pacific Coast of North America, or to a lesser extent in the higher latitude northern perimeter endemic region of the North Pacific. Of the 37 taxa which are amenable to this type of analysis, those with primary Asiatic affinities account for about 32%. Taxa with western North American affinities account for about 35% of the fauna, and species of endemic North Pacific origin account for about 30%. Fourteen percent of the fauna (included with the endemics) is composed of precursors of taxa that later achieved circumboreal distributions. A cosmopolitan species, *Hiatella arctica* (Linnaeus), that forms 3% of the fauna, is the most abundant element in the collections.

The Narrow Cape Formation:

Richly fossiliferous sandstones, siltstones, and conglomerates which crop out along the headland of Narrow Cape on the east side of Kodiak Island have been named the Narrow Cape Formation by Moore (1969). The formation rests with prominent angular unconformity on the Eocene and Oligocene Sitkalidak Formation. MacNeil (1965), Moore (1969), Plafker (1971), Wagner (1974), and Allison & Addicott (1973, 1976) have all referred these strata to the provincial middle Miocene.

The megainvertebrate fauna of the Narrow Cape Formation is poorly known, but consists of at least 80 taxa. Fossil collections have been made by the writer and Carol Wagner Allison in 1969, and by W. O. Addicott, J. Wyatt Durham, Saburo Kanno, and the writer in 1970.

The Narrow Cape Formation belongs to the Newportian Stage (Addicott, 1976; Allison, 1976). *Mytilus middendorffi* Grewingk, which is restricted to the Newportian Stage (Allison & Addicott, 1976), ranges throughout the Narrow Cape Formation. The Newportian Stage is equivalent to the upper Saucesian to the Luisian Stages of the West Coast benthic foraminiferal chronology (Allison & Addicott, 1976), an interval that Berggren & Van Couvering (1974) refer to the late early to early middle Miocene. This age assignment is also confirmed by the known ranges of other molluscan taxa.

The molluscan fauna of the Narrow Cape Formation suggests that deposition occurred within the neritic zone. In the lower coarser-grained portion of the formation, a number of beds are composed primarily of molluscan shells and shell detritus. These shell beds contain abundant *Pseudocardium* and *Mytilus middendorffi*, both with heavy valves, well adapted to wave surge in the inner neritic and shallow subtidal environments. These richly fossiliferous beds may be storm concentrations of shell material. *Kewia kannoi* Wagner is also found here, and is thought to indicate an inner neritic environment.

The upper part of the Narrow Cape Formation is composed of finer-grained more massive sandstone and siltstone, and lacks the prominent shell beds. Fossils are sporadic here; these strata appear to have been deposited in slightly deeper water than existed during deposition of the lower part of the formation. Water depth appears to have been within the outer neritic depth zone and no deeper than about 130 m.

Molluscan assemblages of the Narrow Cape Formation indicate warm water conditions within the warm temperate climatic belt of Hall (1964). Cooler water genera, whose members are not found living in water warmer than the warm temperate zone include *Acila, Clinocardium,* *Cyclocardia, Mya, Colus,* and *Cryptonatica*. Warm-water genera which presently live in water no cooler than the warm temperate zone include *Anadara, Chione,* and *Dosinia*. The presence of the gastropod *Ficus,* which appears to be limited today to the inner and outer tropics, is one of the most convincing indicators of warm water conditions. The Narrow Cape fauna appears to represent the warmest water conditions known among the Oligocene to Recent faunas of the Gulf of Alaska region. ADDICOTT (1969) has discussed this Neogene warm water maximum and its effect on the latitudinal range of *Dosinia* and *Ficus*.

Although the full faunal composition of the Narrow Cape Formation is not yet known, both western North American and Asiatic faunal affinities are apparent. Of the 30 taxa analyzed here, approximately 53% have western North American affinities, about 33% have Asiatic affinities, and about 13% are endemic to the high latitude North Pacific perimeter. One species, *Natica* cf. *N. clausa* (Broderip & Sowerby), (3% of the fauna; included with the endemics) is a precursor of the living circumboreal species.

The Narrow Cape fauna is also notable in that it is different from the contemporary fauna of the lowermost mainland Yakataga Formation in the Yakataga district. In contrast to the Narrow Cape fauna, the Yakataga fauna is a cool-water fauna showing substantial endemism and relationship to the modern cool-water fauna of the Gulf of Alaska. This fact has hindered detailed correlation between the two faunas.

Unga Conglomerate Member of the Bear Lake Formation:

The name "Unga Conglomerate" was proposed by DALL & HARRIS (1892: 234) for brown conglomerates which overlie coal-bearing strata on Unga Island, Alaska. BURK (1965: 92-93) referred to the Unga Conglomerate as a member of his Bear Lake Formation and designated the type section to consist of all the strata exposed west of Zachary Bay. Thus his 244 m thick measured section of the type Unga Conglomerate Member west of Zachary Bay (BURK, 1965: 212) includes not only the coarse conglomerate of Dall and Harris's Unga Conglomerate, but several hundred feet of underlying sandstone, conglomerate, and lignitic leaf-bearing siltstone. The base of the Unga Conglomerate was considered by Burk to be the unconformity between the underlying Stepovak Formation and the lignitic beds; unfortunately, this contact is not exposed at the type locality of the Unga Conglomerate.

The age of the Unga Conglomerate is difficult to determine because diagnostic fossils are rare, but much confusion also stems from mis-allocation of fossil localities and mixing of fossil collections made in the 1800's. Further complications have arisen from the widely reported occurrence of *Mytilus middendorffi* in the coarse clastics of the Unga Conglomerate (ALLISON & ADDICOTT, 1976); although this species is correctly considered to be a provincial middle Miocene (Newportian-Temblor) index species, the Unga Conglomerate *Mytilus* is in fact different, and has been described as *Mytilus gratacapi* Allison & Addicott. MACNEIL (1973) has presented the most inclusive account of Unga Conglomerate fossil mollusks.

Analysis of the known stratigraphic ranges of the few taxa identified suggests that the marine beds of the Unga Conglomerate are no younger than early Wishkahan and no older than late Newportian (Figure 2). All the molluscan taxa reported from the Unga Conglomerate, with the exception of the questionably identified *Epitonium* cf. *E. clallamense* Durham, are compatible with, or restricted to, some part of the Newportian to Wishkahan interval. Only two species, *?Sanguinolaria ochotica* Slodkevich, and *Epitonium* cf. *E. howei* Durham, would indicate restriction to the Wishkahan Stage alone; both taxa are doubtfully identified and weak bases for correlation. Three species indicate an age no younger than Newportian: *?Colus kurodai* (Kanehara), of HIRAYAMA (1955) (see MACNEIL, 1973), possibly *Ocenebra topangensis* Arnold, and *Cyclocardia* cf. *C. kevetscheveemensis* (Slodkevich) (seems to indicate only a late Newportian age). The view that *Mytilus gratacapi* descended from the Newportian *Mytilus middendorffi* (ALLISON & ADDICOTT, 1976) is compatible with a late Newportian age for the Unga Conglomerate Member. Although the evidence favors the late Newportian age, an early Wishkahan age cannot be totally excluded.

The leaf-bearing non-marine beds, which belong to the Seldovian Stage (WOLFE *in* BURK, 1965: 234) are probably not younger than Newportian but could be older (the Homerian-Seldovian Stage boundary is about 12.5 m.y.: personal communication, J. A. Wolfe, Jan., 1976). The presence of Seldovian plant fossils in the Stepovak Formation at Coal Bay (WOLFE *in* BURK, 1965: 88, 233, 234) suggests that these lowermost non-marine strata may be more reasonably referred to the Stepovak Formation.

The Narrow Cape Formation may be partially coeval with the Unga Conglomerate Member, or may be wholly older. The Unga Conglomerate Member appears to be of latest early to middle Miocene age. MACNEIL (1973: 117) has, however, interpreted the Unga Conglomerate fauna to be slightly older.

Although many of the taxa reported here from the Unga Conglomerate Member of the Bear Lake Formation are rather wide ranging in water depth, it is clear that deposition took place under conditions ranging from subaerial to water depths no greater than about 90 m (upper part of the outer neritic zone). Much of the unit was probably deposited in the inner neritic and shallow subtidal part of the inner neritic zone. Fossil wood and upright tree stumps in the Unga Conglomerate of Unga Island (BURK, 1965; EAKINS, 1970) indicate subaerial conditions. A number of small collections of mollusks from the Alaska Peninsula north of Unga Island, however, show the latter area to have been one of marine clastic deposition. The very heavy shell of *Mytilus gratacapi* suggests adaptation to high energy nearshore environments on exposed coastlines with heavy wave surge and surf (ALLISON & ADDICOTT, 1976). The heavy shelled mactrid genus *Pseudocardium* also suggests a nearshore high-energy environment and probably indicates shallow water.

The Unga Conglomerate Member was probably deposited in water of the warm temperate province [no cooler than 10° C surface temperature (HALL, 1964), substantially warmer than that of the present Gulf of Alaska]. The available small molluscan collections suggest that water temperatures were similar during deposition of the Unga Conglomerate Member and during the deposition of the remainder of the overlying Bear Lake Formation.

The very poorly known molluscan fauna of the Unga Conglomerate Member appears to contain faunal elements with both western North American and Asiatic affinities. Of the 17 taxa analyzed here, six (35%) seem to be of Asian affinities, and 4 (24%) seem related to western North American stocks. The remaining 7 taxa (41%) are either locally endemic, or endemic to the higher latitude perimiter of the North Pacific.

Bear Lake Formation, unnamed upper member:

The type locality of the Bear Lake Formation is in the mountains above and eastward from Bear Lake, just east of Port Moller. These marine clastic sedimentary rocks have been mapped by BURK (1965) on the Alaska Peninsula between Cold Bay on the west and Black Peak near Chignik Bay on the east. Bear Lake Formation beds above the Unga Conglomerate Member have not been given a member name. The overlying yellow, brown, or gray lithic subgraywackes, lithic arenites, and shales differ sharply from the volcanic detritus of the basal conglomerate. The Bear Lake Formation is at least 1525 m thick in the vicinity of Port Moller, and may be twice this thick (BURK, 1965). It is unconformably overlain by volcanic breccias, or by marine sandstone and conglomerate which I refer to the Tachilni Formation. In the Black Peak area, beds mapped as Bear Lake Formation by BURK (1965) are now known to contain a major angular unconformity. This feature separates an overlying cool-water molluscan fauna, which I consider correlative of the Tachilni Formation, from an underlying warmer-water molluscan fauna typical of the Bear Lake Formation proper.

The Bear Lake Formation is richly fossiliferous locally. The upper part of the formation contains oysters, clams, and sand dollars which may form shell banks in which fossils constitute as much as a third of the rock volume (BURK, 1965). Nevertheless only meager collections are presently available for study. A megainvertebrate fauna of about 40 species is known from the Bear Lake Formation above the Unga Conglomerate and below the uncomformably overlying strata. There is little doubt that careful collection of the Bear Lake Formation could materially enlarge the faunal list.

MACNEIL (*in* BURK, 1965) and ALLISON & ADDICOTT (1976) have considered the type Bear Lake Formation to be of provincial late Miocene age. My analysis of the molluscan fauna of the upper unnamed member of the Bear Lake Formation below the unconformity shows it to belong to the Wishkahan Stage of ADDICOTT (1976). The Wishkahan Stage is late middle to late Miocene in the sense of BERGGREN & VAN COUVERING (1974). Species which occur in the Bear Lake Formation that are not known in strata older than those of the Wishkahan Stage include *Acila* cf. *A. empirensis* Howe, *Chione* cf. *C. securis* (Shumard), *Clinocardium hannibali* Keen, *Clinocardium* sp. aff. *C. nuttalli* (Conrad), *Clinocardium* cf. *C. pristinum* Keen, *Siliqua* sp. (generic range in Pacific Northwest only), and *Tellina aragonia* Dall. In addition, *Clinocardium hannibali* Keen, *Clinocardium pristinum* Keen, and *Tellina aragonia* Dall are not known from strata younger than those of the Wishkahan Stage.

The molluscan assemblages from the Bear Lake formation are clearly indicative of deposition in the neritic zone; many of the collections are indicative of the inner neritic zone. Some assemblages bearing *Mytilus gratacapi* and *Macrocallista* n. sp. suggest very shallow subtidal deposition.

Bear Lake faunal assemblages whose stratigraphic position is not in doubt give clear indications of water temperatures warmer than at present in the Gulf of Alaska. Although the majority of genera found in the unit still occur at the latitude of the Alaska Peninsula, at least 6 are extralimital thermophiles. These genera are: *Anadara, Macrocallista, Musashia, Chione, Septifer,* and large *Turritella*. *Chione* and *Anadara* suggest water no cooler than warm temperate [no cooler than 10° C surface temperature (HALL, 1964)]. *Musashia* and *Septifer* suggest water no cooler than mild temperate, and large *Turritella* are found no farther north than at the southern limit of the North Pacific cool temperate water mass off Asia. *Macrocallista* is restricted to tropical waters today, but almost certainly inhabited cooler water in the western and eastern North Pacific in the past. No frigophilic extralimital genera are known from the Bear Lake Formation.

The molluscan fauna of the Bear Lake Formation is a mixture of both Asiatic and western North American faunal elements. Approximately 21% of the 29 taxa selected for faunal analysis appear to have Asiatic faunal affinities, and 48% seem related to western North American stocks. Thirty-one percent of the fauna is endemic to the high latitude perimeter of the North Pacific. About 10% of the taxa (included with the endemics) is composed of precursors of species that later achieved circumboreal distributions.

Tachilni Formation:

WALDRON (1961) applied the name "Tachilni Formation" to fossiliferous sandstone, conglomerate, and black shale that crop out along the Pacific coast of the Alaska Peninsula between Thinpoint Cove and Cape Tachilni, near the entrance to Morzhovoi Bay. The Tachilni Formation contains much volcanogenic material in which fossil mollusks occur. To the east, the formation is unconformably overlain by the Morzhovoi Volcanics, but to the west the contact between the two units is gradational. On a regional basis, the Tachilni unconformably overlies the Bear Lake Formation. The thickness is unknown, but at the Cape Tachilni type locality, more than 61 m of richly fossiliferous, poorly consolidated sandstone crops out. Fossiliferous marine sedimentary rocks in the Black Peak-Milky River area of the Alaska Peninsula unconformably overlie the fossiliferous late middle to late Miocene Bear Lake Formation. In the writer's view, these strata are coeval with the Tachilni Formation, although BURK (1965) mapped them as part of his Bear Lake unit.

The megainvertebrate fauna of the Tachilni Formation is poorly known. MACNEIL (1970) described two new mollusks, and WAGNER (1974) described three new echinoids from these beds. I have recognized 19 taxa in Tachilni Formation fossil collections, although the fauna is doubtless larger. Seven species are only known from the Alaska Peninsula. Among the remaining taxa, known occurrences suggest that the Tachilni Formation is no older than the Jacalitos Formation and no younger than the Etchegoin Formation, both of California. *Polinices galianoi* Dall is not known in beds younger than the Etchegoin Formation of the San Joaquin Basin and the basal Merced Formation of central California. *Crenomytilus coalingensis* (Arnold) is known from beds as old as the Jacalitos and Castaic Formations of California and as young as the San Joaquin Clay of the Kettleman Hills, California. *Mya elegans* (Eichwald) suggests that the Tachilni Formation is no older than the Jacalitos Formation of California because MACNEIL (1965, p. G-23, G-30) has interpreted it to be a descendant of the provincial late Miocene Neroly Formation species, *Mya dickersoni* Clark. *Remondella waldroni* Wagner occurs with *Echinarachnius* cf. *E. ungaensis* Wagner and seems to be closely related to the only other known species of *Remondella, R. gabbi* (Remond) from the provincial late Miocene of California (Cierbo through uppermost Neroly Formations of Mt. Diablo area). WAGNER (1974) notes that *R. waldroni* is more highly evolved, and therefore presumably younger, than *R. gabbi*.

Although MACNEIL *et al.* (1961), MACNEIL (1970), and WAGNER (1974), have referred the Tachilni Formation to the provincial early Pliocene, the formation is here regarded as late Miocene. The Jacalitos to Etchegoin interval is probably best referred to the upper Mohnian to lower Delmontian benthic foraminifer Stages, approximately correlated with the Graysian molluscan Stage of the Pacific Northwest (ADDICOTT, 1976: 98). Because the lower part of the San Joaquin Formation, which overlies the Etchegoin Formation of California, has been radiometrically dated at 4.3 m.y. (REPENNING, 1976: 310), it is probable that the Etchegoin Formation is best referred to the latest Miocene. ADDICOTT (1976: 96 and 110) also provisionally places the Graysian Stage in the latest Miocene. For these reasons, the Tachilni Formation is here regarded as the latest Miocene, although the Miocene-Pliocene boundary may fall within it.

The Tachilni fauna appears to represent the shallow subtidal part of the inner neritic environment. Taxa whose modern analogs are restricted to shallow water include: *Kewia, Spisula, Crenomytilus, Macoma* cf. *M. nasuta* (Conrad), *Siliqua, Protothaca,* and *Mya elegans* (Eichwald). In particular, *Mya elegans* is restricted to the shallow subtidal part of the inner neritic zone.

The mollusks of the Tachilni Formation indicate cool temperate water conditions similar to the present Gulf of Alaska. Many genera are wide ranging thermally, but *Beringius, Spisula voyi* (Gabb) and *Mya elegans* are northern cool-water taxa. CHAMBERLAIN & STEARNS (1963) considered *Spisula voyi* to be conspecific with *S. polynyma* (Stimpson) and report that this pelecypod is thermally limited by water warmer than about 13° C mean annual temperature. No uniquely warm-water taxa are known from the Tachilni Formation.

The small sample of the Tachilni molluscan fauna suggests that about 21% of the species are related to taxa from the west coast of North America, and that about 63% are endemic to the higher latitude perimeter of the North Pacific. About 16% of the taxa are related to Asian species, and about 26% of the fauna (included with endemics) have affinities with North Atlantic stocks which probably descended from Pacific progenitors, possibly the Tachilni taxa themselves.

Tugidak Formation:

The Tugidak Formation is a 1 500 meter-thick sequence of interbedded sandstone, siltstone, and conglomeratic sandy mudstone which crops out along the coastal bluffs and intertidal reefs of Tugidak and Chirikof islands, Alaska (MOORE, 1969). These strata contain randomly distributed pebbles and cobbles of glacial-marine origin. The base of the formation is not exposed. Unnamed marine Pleistocene beds conformably overlie the Tugidak Formation on Chirikof Island (MOORE, 1969). MACNEIL (*in* MOORE, 1969), ADDICOTT (*in* MOORE, 1969) and PLAFKER (1971) have all considered the Tugidak Formation to be Pliocene. About 20 fossil collections have been examined by the writer. They show the fauna to be diverse (more than 80 species) and largely composed of living, cold-water, North Pacific and Arctic taxa.

No satisfactory biostratigraphic standard yet exists for western North American late Neogene offshore molluscan faunas, which makes interpretation of the precise age and correlation of the Tugidak fauna difficult. Accordingly, the age of the Tugidak fauna is best determined with reference to the late Pliocene and Pleistocene transgressions of Beringia (HOPKINS, 1967, 1973; HOPKINS *et al.*, 1974). No paleomagnetic geochronologic data are presently available for the Tugidak Formation.

The few extinct species in the Tugidak fauna indicate the best comparison to be with faunas of the late Pliocene Beringian and early Pleistocene Anvilian transgressions. The following Tugidak taxa have their first known appearance in strata of Beringian age: *Astarte elliptica* (Brown), *Astarte hemicymata* Dall, *Astarte montagui* (Dillwyn), *Astarte* cf. *A. nortonensis* MacNeil, *Astarte rollandi* Bernardi, *Buccinum* cf. *B. glaciale* Linnaeus, *Colus* cf. *C. spitsbergensis* (Reeve), *Epitonium greenlandicum* (Perry), *Epitonium greenlandicum smithi* MacNeil, *Plicifusus* cf. *P. brunneus* (Dall), *Polinices pallidus* (Broderip & SOWERBY), *Tachyrhynchus erosus* (Couthouy), and *Volutopsius* aff. *V. stefanssoni* Dall.

Although there is good evidence that the Tugidak fauna is no older than the Beringian transgression of late Pliocene age, the upper age limit is more difficult to establish. The presence of the very distinctive *Astarte hemicymata* in the Tugidak fauna is clear evidence of a Beringian to Anvilian late Pliocene to early Pleistocene age. *Astarte* cf. *A. nortonensis* indicates a Beringian to Einahnuhtan age. Comparison of the molluscan fauna to the Bering Sea transgressions standard does not, however, permit recognition of the Beringian or Anvilian intervals by themselves. Therefore, it is not clear whether the Tugidak Formation is totally of late Pliocene age, totally of early Pleistocene age, or whether it contains the Pliocene-Pleistocene boundary. Fossil pectinids suggest that the upper part of the Tugidak Formation correlates with the lower part of the Yakataga Formation on Middleton Island (MACNEIL & PLAFKER *in* MOORE, 1969) and the Middleton Island section is of demonstrable Pleistocene age (PLAFKER & ADDICOTT, 1976; Plafker, oral communication, November, 1975). Available data therefore suggest that the Tugidak Formation is of late Pliocene and Pleistocene age.

Analysis of depth ranges of taxa from 20 fossil localities representing 18 different stratigraphic levels in the Tugidak Formation suggests that deposition took place in the upper part of the outer neritic zone. Eleven assemblages indicate maximum depths no greater than 145 m, and one suggests water no deeper than 111 m. Three assemblages suggest water depths no shallower than about 119 m and 5 others indicate water no shallower than about 37 m. All the assemblages studied are compatible with neritic water depths between 91 and 145 m.

Tugidak Mollusca clearly represent cold-water conditions, colder than the present Gulf of Alaska. It seems likely that the Bering Strait was open and that there were marine connections through the Arctic to the Atlantic. Species of Atlantic origin (DURHAM & MACNEIL, 1967) include *Astarte elliptica* (Brown), *Astarte montagui* (Dillwyn) [=*A. fabula* Reeve], *Hiatella arctica* (may have reached the Pacific in the tropics rather than through the Arctic, however), and *Moelleria costulata* (Möller). OCKELMANN (1954) has suggested that *Yoldia myalis* (Couthouy) also originated in the Atlantic Ocean. Several circumboreal species in the Tugidak Formation suggest that the water temperature was cooler than that at Tugidak today. These species, which do not now range as far south as Tugidak Island, include *Axinopsida* cf. *A. orbiculata* (Sars), *Nuculana pernula* (Möller), *Yoldia hyperborea?* Torrell, *Boreotrophon clathratus* (Linnaeus), *Boreotrophon truncatus* (Strøm), *Buccinum* cf. *B. angulosum normale* Dall, *Moelleria costulata* and *Velutina undata?* Brown. Extralimital warm-water taxa are not known from the Tugidak Formation.

The Tugidak fauna is of North Pacific origin with approximately 83% of the fauna endemic to the high latitude perimeter of the North Pacific Ocean and the Bering Sea. Forty-six percent of the fauna (included with the endemics) have circumboreal distributions, and about 10% of the fauna seems to have western North American affinities.

Only about 5% of the taxa (some pectinids) suggest primary Asiatic relationships, and one species (1% of those analyzed) is cosmopolitan.

NORTHEASTERN GULF of ALASKA STRATIGRAPHIC UNITS

The Poul Creek Formation:

The Poul Creek Formation was named by TALIAFERRO (1932) from exposures of marine sedimentary rocks which crop out along Poul Creek in the Robinson Mountains of the Yakataga District, Alaska. The formation is composed of reddish-brown-weathering massive concretionary siltstone, sandy mudstone, and fine- to medium-grained sandstone. Glauconitic sandstone is locally abundant. The upper part contains a massive non-resistant siltstone which forms a prominent topographic swale along the front of the Robinson Mountains eastward from Yakataga Reef and a prominent covered interval at the reef itself. The 1859 meter-thick formation (MILLER, 1957) is thought to overlie the Paleogene Kulthieth Formation conformably, and is conformably overlain by the Yakataga Formation in the vicinity of Cape Yakataga. The most continuous section is exposed in a south-facing cliff at the head of Yakataga Glacier in the Robinson Mountains. MILLER (1961: 242) notes that the contact with the overlying Yakataga Formation is gradational through a 15 to 61 meter interval in most places in the Yakataga District.

The contact between the Poul Creek and overlying Yakataga Formation has been variously placed by different authors. Field examination of the contact in several sections of the Robinson Mountains by C. Ariey and the writer confirms MILLER's (1961) view that the contact is gradational. In the gradational interval, glauconitic sandstone and rusty-weathering siltstone of typical Poul Creek lithology alternate with typical Yakataga Formation lithology of gray-weathering sandstone containing scattered pebbles. This gradational interval generally coincides with a change in the molluscan fauna. The formational contact is best defined within the gradational interval at the most prominent break between pebble-bearing sandstones above, and rusty-weathering glauconitic siltstones or sandstones below (C. Ariey, pers. commun., 1974). Use of these criteria at Yakataga Reef places the boundary above KANNO's (1971) contact, and below KANNO's (1971) interpretation of MILLER's (1957) boundary; it is therefore here considered to be at a point about 41 meters above the prominent covered interval (C. Ariey, personal communication, 1974). PLAFKER & ADDICOTT (1976: 5) advocate similar criteria for the formational boundary.

The Poul Creek contains a fairly large molluscan fauna. Using the upper formational boundary advocated here, I have compiled a faunal list of 87 megainvertebrate taxa from University of Alaska collections and published reports [CLARK (1932), DURHAM (1937), PARKER (1949), MILLER (1961), MACNEIL (1961, 1965, 1967), ADEGOKE (1967), MACNEIL *in* MILLER (1971), KANNO (1971), ADDICOTT *et al.* (1971), KANNO (1973), and ADDICOTT (1976)].

Analysis of the molluscan assemblages and species ranges shows that the uppermost strata belong to the Pillarian Stage (ADDICOTT, 1976: 101-102). Species not known to range into strata younger than the Pillarian Stage include: *Acila gettysburgensis* (Reagan), *Pitar arnoldi* (Weaver), *Solemya dalli* Clark, *Vertipecten fucanus* (Dall), *Ancistrolepsis rearensis* (Clark), *Epitonium clallamense* Durham, and *Priscofusus stewarti* (Tegland). *Anadara* aff. *A. osmonti* (Dall) and *Vertipecten fucanus* (Dall), which occur in the upper Poul Creek, are not known to occur in beds older than the Pillarian Stage.

The oldest dated beds of the Poul Creek belong to the *Echinophoria dalli* Zone (ARMENTROUT, 1975), but a refined age for the Kulthieth-Poul Creek boundary is not yet available. It should be noted that many molluscan taxa reported by KANNO (1971) are from stratigraphically lower beds exposed in the Sullivan Anticline, but these beds are not in the lowermost part of the formation which crops out at the head of Yakataga Glacier, in the Grindle Hills, and along the Kosakuts River (KANNO, 1971: 14). The following species, from the lowermost Poul Creek Formation, are not known to range into strata older than those of the *Echinophoria dalli* Zone: *Cyclocardia* aff. *C. hannibali* (Clark), *Panopea snohomishensis* Clark, *Pitar* aff. *P. dalli* (Weaver), *Solena* aff. *S. eugenensis* (Clark), *Thracia* cf. *T. condoni* Dall, *Molopophorus stephensoni* Dickerson, *Perse olympicensis* Durham, and *Perse olympicensis quimperensis* Durham. Species which occur in the lowermost Poul Creek Formation and are not known in beds younger than the *Echinophoria dalli* Zone include *Nemocardium weaveri* (Anderson & Martin), *Solen townsendensis* Clark, *Molopophorus stephensoni* Dickerson, *Perse olympicensis* Durham, and *Perse olympicensis quimperensis* Durham.

MILLER's (1961: 243-245) report of *Patinopecten* (*Lituyapecten*) from the uppermost part of the Poul Creek Formation can be disregarded because these strata are now included in the basal part of the overlying Yakataga Formation. ADDICOTT (1972: 12) notes that *Patinopecten* has its earliest occurrence in the "Temblor Stage" (=Newportian Stage) of California. The appearance of *Patinopecten* (*Lituyapecten*) in the basal beds of the Yakataga Formation is taken here to mark the beginning of Newportian time.

Following BERGGREN & VAN COUVERING'S (1974) chronology, the Poul Creek Formation ranges in age from the late Eocene (upper Refugian benthic foraminifer Stage) to the early Miocene (lower Saucesian benthic foraminifer Stage).

Evaluation of Poul Creek molluscan assemblages indicates that deposition took place in the lower inner neritic and outer neritic depth zones. Among 10 assemblages which contain genera suggestive of minimal water depth, 2 indicate water no shallower than about 21 meters, 6 no shallower than 37 meters, and 2 no shallower than 50 meters. Four assemblages indicate water depths no greater than about 111 meters, 3 no deeper than 143 meters, 1 no deeper than 165 meters, and 3 no deeper than 186 meters. RAU (1963) infers water depths between 61 and 244 meters (outer neritic to uppermost bathyal) from a benthic foraminiferal assemblage near the top of the formation.

The Poul Creek fauna is indicative of warm-water similar to the present North Pacific warm temperate belt (HALL, 1964). The oldest fossil assemblages include the genera *Nemocardium, Solen, Turritella, ?Cylichna, ?Exilia, ?Parvicardium, ?Pitar* and *?Spisula,* as well as the extinct gastropods *Molopophorus* and *Perse;* these taxa appear to indicate a warm temperate marine climate.

Several genera in the middle to upper parts of the formation indicate temperatures no cooler than the warm temperate zone; these are: *Crassatella, Macrocallista, Papyridea,* and *Eosiphonalia.* Genera which suggest temperatures no warmer than the warm temperate zone include *Clinocardium, Cyclocardia, Mya, Nemocardium, Ancistrolepsis, Bathybembix, Colus, Natica (Cryptonatica),* and *Pteropurpura.* The youngest (Pillarian) Poul Creek strata also contain very large specimens of *Panomya arctica* (Lamarck) (C. Ariey, personal communication, 1975), a species which does not range into water warmer than that of the mild temperate zone today. Some evidence suggests the beginning of cooling conditions during latest Poul Creek time; the bulk of the data, however, indicate the Poul Creek molluscan faunas to be of warm temperate character.

The Poul Creek fauna is most closely related to that of the Tertiary of the Pacific northwest coast of North America. Approximately 52% of the Poul Creek species have western North American affinities and about 18% of the fauna is related to that of Asia. Approximately 30% of the Poul Creek fauna was locally endemic, or was distributed around the high latitude North Pacific perimeter. Six percent of the fauna (included with the endemics) is composed of precursors of taxa that later achieved circumboreal distributions. Although these numbers differ somewhat from those of KANNO (1971: 17), they suggest the same relative weighting between North American, Asian, and endemic faunal elements.

The Yakataga Formation:

The Yakataga Formation was named by TALIAFERRO (1932) for "a thick series of sandstones, dark shales, and conglomerates" which overlies the Poul Creek Formation at Yakataga Reef and in the Sullivan Anticline area of the Robinson Mountains. PLAFKER & ADDICOTT (1976: 6) have designated the type section as an 1 800 meter-thick sequence of beds between the contact of the Poul Creek Formation at the head of Poul Creek and the southern margin of Guyot Glacier north of Munday Peak. The Yakataga Formation extends over a broad area of the northeastern Gulf of Alaska, from the Suckling Hills of the Katalla district on the west to Icy Point in the Lituya district on the east. It also crops out on Kayak, Middleton, and Wingham islands, and probably occurs over much of the adjacent continental shelf of the Gulf of Alaska (*op. cit.*, p. 4). It has a composite thickness of about 5 000 m (*op. cit.*) of which the upper 1181 m are exposed on Middleton Island (PLAFKER, 1971). A major intraformational unconformity occurs within 1500 m of the base of the formation in the Yakataga-Malaspina districts (ADDICOTT & PLAFKER, 1976: 15). Till-like glaciomarine diamictite or "conglomeratic sandy mudstone" occurs in all but the basal part, and is abundant in much of the formation (*op. cit.*, p. 9). Glaciomarine dropstones occur in all lithologies and are primary components of the diamictites. Glacial striae are observed on scattered clasts (*op. cit.*, p. 9b-10).

Although the youngest outcrops are on Middleton Island, marine seismic profiling and bottom sampling indicate that the youngest part of the formation includes unlithified Holocene deposits (PLAFKER & ADDICOTT, 1976: 6). The oldest strata assigned to the Yakataga Formation occur on Kayak Island (PLAFKER, 1974; PLAFKER & ADDICOTT, 1976) and are older than the basal Yakataga Formation beds at Yakataga Reef and in the Sullivan Anticline area.

This section of the paper deals primarily with the pre-Pleistocene faunas of the Yakataga Formation of the Katalla, Yakataga, Malaspina, Yakutat, and Lituya districts. The Pleistocene portion of the Yakataga Formation at Middleton Island is treated separately.

The oldest strata recognized in the formation occur on Kayak and Wingham islands. Although a number of molluscan taxa are reported from Kayak and Wingham islands by ADDICOTT *in* PLAFKER (1974), only two stratigraphically significant species, *Acila gettysburgensis* (Reagan) and *So-*

lemya dalli Clark, occur in these strata. The co-occurrence of these taxa in the "lower part of the Yakataga Formation" (PLAFKER, 1974), south of the Kayak Fault on eastern Kayak Island, indicates a Juanian to Pillarian age, that is, latest Oligocene to early Miocene in the sense of BERGGREN & VAN COUVERING (1974). PLAFKER (1974) reports a sparse foraminiferal assemblage of possible Zemorrian, and therefore probable, Juanian age.

Slightly younger strata on Kayak Island, referred to the "upper part of the Yakataga Formation" (PLAFKER, 1974) also contains *Acila gettysburgensis*. The co-occurrence of this species, which is not known to range into strata younger than Pillarian age (ADDICOTT, 1976b) with foraminiferal assemblages of Saucesian or Relizian age (PLAFKER, 1974) suggests that these strata belong to the Pillarian Stage of the early Miocene. Recognition of Juanian (?) and Pillarian strata in the lower Yakataga Formation indicates that the upper Poul Creek Formation of the Yakataga area and the lower Yakataga Formation of Kayak Island are coeval.

Strata near the base of the Yakataga Formation at Yakataga Reef are here considered to belong to the late early to early middle Miocene Newportian Stage. The Newportian age is based on the presence of *Macoma arctata* (Conrad) (KANNO, 1971, loc. 80605), which is not known to occur in strata younger than those of Newportian age, and the genus *Patinopecten* which is not known to occur in strata older than those of the Newportian Stage (ADDICOTT, 1974: 183; 1976: 98). The lowest known stratigraphic occurrence of *Patinopecten* at the reef seems to be that of KANNO (1971: 53, and USGS loc. M271, probably equal to Kanno's loc. 80903). This locality is approximately 10 meters above the Poul Creek-Yakataga contact, as used here (see discussion under Poul Creek Formation) or about 51 m stratigraphically above the prominent covered shale of the upper Poul Creek Formation at the reef (measured section of C. Ariey, personal communication, August, 1976). PLAFKER & ADDICOTT (1976) also list *Molopophorus matthewi* Etherington from the lower Yakataga Formation in the Yakataga district; although the exact stratigraphic position is not reported, this species is considered to be restricted to the Newportian Stage.

Unpublished research by C. Ariey (personal communication, June, 1977) suggests that the Newportian-Wishkahan boundary is located approximately 30 m above the base of the Yakataga Formation, and that Newportian strata therefore constitute a very thin stratigraphic interval in the Yakataga District. This conclusion is based upon the first appearance of *Siliqua* and *Yoldia* (*Cnesterium*) which are thought to be indicative of strata no older than the Wishkahan Stage in the northeastern Pacific. Other modern taxa which first appear in this stratigraphic position include *Mya truncata* Linnaeus, *Solamen* cf. *S. columbianum* (Dall), *Miyagipecten* sp., *Yabepecten* sp., *Laqueus californianus* (Koch). and *Bittium* cf. *B. frankeli* Faustman (personal communications, C. Ariey and S. McCoy, Jan., 1978).

Deposits of Wishkahan, Graysian, Moclipsian, and younger are clearly present in the Yakataga Formation, but the boundaries between these stages, as well as those of the European series-epochs, are presently extremely difficult to place. This stems from lack of published faunal lists for specific fossil localities of known stratigraphic position in the part of the formation stratigraphically above Yakataga Reef, as well as from the increase of endemic and living species in these younger strata. PLAFKER & ADDICOTT (1976: 22) observe that correlation is also hindered by the tendency of late Cenozoic cold-water mollusks to be unusually long-ranging.

WAGNER (1974) notes the presence of *Scutellaster oregonensis* (Clark) in the Yakataga Formation of the La Perouse Glacier and Topsy Creek areas of the Lituya District. This species is restricted to strata of Wishkahan age in the Pacific Northwest. MASUDA & ADDICOTT (1970) questionably report *Yabepecten condoni* (Hertlein) [=? *Miyagipecten alaskensis* MacNeil] from a nunatak north of the east end of the Pinnacle Hills in the Malaspina district; this species appears to be restricted to deposits of Graysian age (ADDICOTT, 1976). MACNEIL (1961) reported *Patinopecten* (*Lituyapecten*) cf. *P.* (*L.*) *dilleri* (Dall) from the coast south of Lituya Bay; *P.* (*L.*) *dilleri s. s.* is restricted to deposits of Moclipsian age (ADDICOTT, 1976). Although the geographic occurrence is unknown, the appearance of a species of Atlantic origin, *Astarte* aff. *A. elliptica* (Brown) [= *A. alaskensis* Dall], about 2438 m above the base of the Yakataga (MACNEIL *in* MILLER, 1971; MACNEIL, 1965: 6-8) is indicative of a Beringian or younger age. Many other molluscan taxa indicative of Beringian and younger ages occur in the upper Yakataga Formation of the mainland. *Chlamys chaixensis* MacNeil and *Chlamys lioica* (Dall) co-occur in the highest Yakataga strata in the Chaix Hills of the Malaspina District; these beds are no older than the Beringian transgression, and are probably Anvilian (early Pleistocene) in age (PLAFKER & ADDICOTT, 1976). These strata may be younger than the *Chlamys* (*Leochlamys*) *tugidakensis* range zone of Tugidak and Middleton Islands.

In summary, the oldest strata of the Yakataga Formation occur on Kayak Island; they are at least as old as the Pillarian Stage, and could be as old as the Juanian Stage. The youngest Yakataga strata in the Yakataga to Lituya districts are probably coeval with the Middleton Island Anvilian beds and could be in part younger than the *Chlamys* (*Leochlamys*) *tugidakensis* Range Zone. The Yakataga

Formation therefore appears to range from late Oligocene (?) or early Miocene (Juanian? to Pillarian) to early Pleistocene (Anvilian).

The oldest Yakataga strata, at Kayak and Wingham islands, were deposited in upper bathyal water depths. The lower Yakataga of the Yakataga District seems to have been deposited in lower inner neritic to outer neritic water depths. Younger parts of the formation in the Malaspina to Lituya districts to the southeast may be inner neritic. The youngest beds of the formation at Kulthieth Mountain and Pinnacle Pass appear to be intertidal to shallow sublittoral deposits. It therefore appears that water depth became generally shallower upsection. Although not as well documented, there also seems to be a trend from deeper water offshore to shallower water onshore in the north and easterly directions.

Yakataga molluscan faunas clearly indicate cooler water than that of the underlying Poul Creek Formation. Mollusks from the lowermost part of the Yakataga Formation on Kayak Island (Juanian? Stage) appear to indicate mild temperate conditions, probably slightly cooler than those during deposition of contemporary strata of the Yakataga District. This apparent discrepancy probably reflects the deeper, and therefore cooler, environment of deposition at Kayak Island. The "upper part of the Yakataga Formation" (PLAFKER, 1974) at Kayak Island (Pillarian Stage) and Pillarian strata of the Poul Creek Formation in the Yakataga District also seem to have been deposited in mild temperate water. Yakataga molluscan assemblages reported by KANNO (1971) from Yakataga Reef (Newportian and probably Wishkahan) suggest slightly cooler temperatures, probably like those near the mild temperate-cool temperate boundary. A number of small collections from the lower Yakataga of the Sullivan Anticline and Yakataga District (KANNO, 1971) also suggest mild temperate to cool temperate conditions.

Stratigraphically higher beds in the Karr Hills and the Samovar Hills (KANNO, 1971) probably were deposited in cool temperate water; these strata appear to be no older than Graysian (late Miocene). Strata which appear to be no older than the late Pliocene Beringian transgression also contain molluscan assemblages indicative of water no warmer than the cool temperate climatic zone.

Yakataga molluscan assemblages therefore demonstrate that climatic deterioration continued during Miocene and Pliocene time. By early Pleistocene (Anvilian) time, the molluscan data indicate the presence of cold-water conditions (see section on Middleton Island Yakataga Formation).

All workers who have considered the paleoclimatology (e.g. BANDY *et al.*, 1969; KANNO, 1971; PLAFKER & ADDICOTT, 1976) agree that there was a temperature drop during late Poul Creek to earliest Yakataga time. My interpretation of the Yakataga molluscan and planktonic foraminifer data is, however, in disagreement with the views of earlier workers in that I believe mild temperate and cool temperate rather than cold (Arctic) conditions existed throughout much of Yakataga time.

KANNO (1971:24) suggests that the entire Yakataga Formation was deposited in "Arctic" water temperatures comparable to those north of the present southern limit of winter sea ice. PLAFKER & ADDICOTT (1976) refer to a sharp decline in temperature across the formational contact from "temperate" to "cold" conditions, but do not specify how cold the Yakataga may have been.

BANDY *et al.* (1969) offer an interpretation similar to KANNO (1971) in suggesting a 10° to 15° C temperature drop across the formational boundary. This interpretation is based on an influx of left-coiling *Turborotalia pachyderma* (Ehrenberg) near the base of the Yakataga Formation in the Yakataga District. BANDY *et al.* (1969) indicate that this planktonic foraminifer is similar to those now restricted to polar waters with summer surface temperatures of about 2° C.

HERMAN (*in* ALLISON, 1973) points out, however, that the range of sinistral *T. pachyderma* is between −1° C and 5° C, but that it is occasionally found in waters up to 15° C. BANDY (1968b) notes the common occurrence of predominantly sinistral *T. pachyderma* in waters with 2° to 8° C summer temperatures, and BANDY (1968a) also points out that the southern boundary of the common sinistral *T. pachyderma* fauna appears to be about 45° north latitude in the eastern Pacific off Oregon, and perhaps near 50° north latitude in the central and western Pacific. These latitudes embrace the cold or Arctic zone, the cool temperate zone, and parts of the mild temperate belt. On the basis of my study of the Mollusca and data (BANDY, 1968a, 1968b; HERMAN *in* ALLISON, 1973) on *Turborotalia pachyderma* it does not appear to me that the cold water (Arctic) paleotemperature interpretations for the bulk of the Yakataga Formation are defensible. Both the molluscan and planktonic foraminifer data are compatible with mild temperate to cool temperate conditions suggested here for the pre-Beringian portions of the formation. The Beringian and Anvilian parts of the formation, however, do appear to have been deposited in cold (Arctic) waters.

Although the Yakataga molluscan fauna is incompletely known, some general paleozoogeographic trends are indicated. About 41% of the taxa of the lower Yakataga Formation at Kayak and Wingham Islands is composed of species with Asiatic affinities. Asiatic paleozoogeographic affinities are less apparent in the younger (Newportian and

Wishkahan?) beds at Yakataga Reef (about 12%) and in strata younger than those of Yakataga Reef (Graysian? and younger) (about 10%). Faunal affinities with the west coast of North America increase slightly from about 14% at Kayak and Wingham islands to about 28% at Yakataga Reef and about 26% for younger strata.

The fauna of the Yakataga Formation is marked by the large number of taxa which are endemic to the high latitude perimeter of the North Pacific or to the local outcrop area. Endemic species constitute about 45% of the fauna at Kayak and Wingham islands and increase to about 58% at Yakataga Reef. Strata younger than those of Yakataga Reef contain faunas with about 62% endemic taxa.

Of interest is the number of precursors to present circumboreal taxa in the Yakataga Formation. In fact, the Kayak and Wingham islands Yakataga faunas include two taxa (about 9% of the fauna; included with the endemics) that probably are ancestral to modern circumboreal species. Five of the endemic taxa (12% of the fauna) from Yakataga Reef also appear to be precursors of present circumboreal taxa. About 26% (included with the endemics) of the Yakataga fauna from strata younger than those at Yakataga Reef show circumboreal paleozoogeographic affinities.

One cosmopolitan species, *Hiatella arctica,* (2% of the fauna) occurs at Yakataga Reef, and another, *Mytilus edulis,* (3% of the fauna) occurs in Yakataga strata younger than those of Yakataga Reef.

The large endemic component of the faunas (62% of the fauna in strata younger than those at Yakataga Reef) creates a major problem in correlation of these strata with coeval deposits of the west coast of the conterminous United States.

Yakataga Formation on Middleton Island:

Late Cenozoic glaciomarine strata crop out in the coastal bluffs and on the intertidal platforms of Middleton Island, which is located in the north-central Gulf of Alaska. PLAFKER (1971) assigned these strata to the uppermost Yakataga Formation and reports their thickness to be 1181 m. Marine fossils are sparsely distributed throughout the formation in conglomeratic sandy mudstone, fine-grained sandstone and in siltstone.

Although a number of investigators have variously regarded the Middleton Island Yakataga beds as Pliocene or Pleistocene (MILLER, 1953; MACNEIL, *et al.*, 1961; HOPKINS, 1967; MACNEIL, 1967; ADDICOTT, 1971), there is no convincing biostratigraphic means of recognizing the Pliocene-Pleistocene boundary in the Gulf of Alaska region. PLAFKER & ADDICOTT (1976) and Plafker (personal communication, Nov., 1975) report that recent geomagnetic stratigraphy studies show the Middleton Island Yakataga Formation to belong to the Matuyama reversed polarity epoch (no younger than 0.7 million years b.p.). The very lowest strata exposed at Middleton Island possess normal geomagnetic polarity, possibly indicating the Olduvai event of earliest Pleistocene time (−1.6 to 1.8 m.y.; BERGGREN & VAN COUVERING, 1974: 140). The Middleton Island section is therefore here considered to be of Anvilian (early Pleistocene) age with the Pliocene-Pleistocene boundary near, but below, its base.

About 65 fossil collections from the Middleton Island Yakataga Formation have been examined. Many of these are small, but they range throughout the stratigraphic section. These collections show the fauna to be somewhat less diverse (in excess of 70 species) than that of the Tugidak Formation, and on the whole not as well preserved. The molluscan fauna is largely composed of living cold-water North Pacific and boreal species, and contains about 35 taxa in common with the Tugidak Formation. This difference in faunal composition probably owes in part to difference in geological age as suggested by the distinct *Chlamys* and *Astarte* species; a more fundamental cause, however, probably is the somewhat different ecologic setting at Middleton.

The fossil Mollusca clearly indicate that the Middleton Island Yakataga Formation is younger than the Tachilni Formation of the Alaska Peninsula, and that it is no older than the Beringian transgression. The following species, which occur, or are questionably reported, in the Middleton Island section, make their earliest appearance in strata of Beringian age: *Astarte elliptica* (Brown), *Astarte montaguii* (Dillwyn), *Astarte rollandi* Bernardi, *Buccinum glaciale* Linnaeus, *Buccinum glaciale parallelum* Dall, *Buccinum physematum* Dall, *Buccinum plectrum* Stimpson, *Epitonium greenlandicum* (Perry), *Plicifusus kroyeri* (Möller), *Polinices pallidus* (Broderip & Sowerby), and *Tachyrhynchus erosus* (Couthouy).

Although the lower age limit for this fauna is readily established with the fossil Mollusca, recognition of the upper age limit depends upon the presence of extinct species. Monographic treatment of the pectinids by MACNEIL (1967) and the neptuneids by NELSON (1974) make possible the recognition of the only extinct taxa so far known in the Middleton Island Yakataga Formation. The following extinct species have been recognized: *Chlamys hanaishiensis amchitkana* MacNeil, *Chlamys islandica kanagae* MacNeil, *Chlamys* cf. *C. picoensis chinkopensis* Masuda & Sawada, *Chlamys pseudoislandica plafkeri* MacNeil, *Chlamys coatsi middletonensis* MacNeil, *Chlamys tugidakensis* MacNeil, and *Neptunea lyrata altispira* Gabb.

These taxa indicate an age no younger than the middle Pleistocene Kotzebuan or Einahnuhtan transgressions (HOPKINS, 1973), but the paleomagnetic evidence of an age no younger than the early Pleistocene part of the Matuyama reversed polarity epoch (Anvilian transgression) is thought to be the most reliable criterion for dating this sequence.

Although early collections studied by MacNeil (1967) showed *Chlamys tugidakensis* to range only through the lower 762 m of the Middleton Island section, it is now recorded to approximately 1109 m above the base, and therefore almost throughout the entire stratigraphic succession, a situation also found at Tugidak. In short, both the Middleton Island Yakataga Formation and the Tugidak Formation belong almost entirely to the range zone of *Chlamys tugidakensis* and this species appears to continue across the Pliocene-Pleistocene boundary. Strata of the upper Yakataga Formation in the Chaix Hills of the Lituya District also belong to the range zone of *Chlamys tugidakensis*.

Chlamys cf. *C. picoensis chinkopensis* occurs from near the base of the Middleton Island section to about 732 m above the base. This species also is known from a locality 97.5 m below the top of the Tugidak Formation, which suggests that the top of the Tugidak Formation and some part of the basal Middleton Island Yakataga Formation section may be coeval. The absence of species of *Astarte* in the Middleton Island section, which are restricted to the Beringian-Anvilian interval in the Bering Sea area and at Tugidak, also suggests that much of the Middleton Island section may be younger than the Tugidak Formation.

Analysis of the Middleton Island assemblages shows 8 with lower depth limits of 50 m, 3 with depth limits at 55 m, 11 with limits no deeper than 74 m, and one each limited to water no deeper than 75 m, 119 m, and 136 m. Five assemblages appear to be limited to water no deeper or no shallower than about 50 m.

Analysis of the Middleton Island molluscan assemblages also shows 7 with water no shallower than 15 or 18 m, 5 limited to water no shallower than depths between 21 and 46 m, and most significantly, 16 assemblages limited to water no shallower than 50 m. One assemblage appears to be limited to depths no shallower than 55 m, 64 m, 76 m, and 94 m.

To summarize, these data suggest that most assemblages lived between 50 and 74 m, and that locally the bottom could have been as shallow as 15 or 18 m, and as deep as 136 m at one stratigraphic level near the base of the exposed section. The bulk of the data therefore suggests depths in the lower part of the inner neritic or top of the outer neritic depth zones. The data also suggest that water depths were generally shallower at Middleton Island than at Tugidak, and this appears to have been a significant factor in determining the somewhat different faunas of the two areas.

Mollusks from the Middleton Island Yakataga Formation represent cold-water conditions, colder than exist in the Gulf of Alaska today. Although most of the species are endemic to the North Pacific, my data show that about 35% (included with the endemics) are circumboreal taxa that range throughout the Arctic or into the North Atlantic. Eight species found in the Middleton Island strata are not presently known to live near Middleton, but are confined to areas farther west along the Aleutians or farther north in the Bering Sea. These cold-water extralimital taxa are: *Nuculana pernula* (Möller), *Yoldia* cf. *Y. arctica* (Gray), *Beringius frielei* Dall, *Buccinum tenue lyperum* Dall, *Volutopsius* cf. *V. middendorffi* (Dall), and *Volutopsius* cf. *V. simplex* Dall. Two species in the Yakataga Formation at Middleton Island have not been reported living this far north. These two southern extralimital species are *Laqueus californianus* (Koch) (known as far north as British Columbia), and *Taranis strongi* (Arnold) (known to 55° N latitude at Forrester Island, Alaska). In summary, the evidence suggests that the Gulf of Alaska was indeed colder than at present during deposition of the Middleton Island Yakataga Formation.

As in the Tugidak fauna, most of the Middleton Island Yakataga fauna is of North Pacific origin. Approximately 75% of the taxa have modern North Pacific distributions suggesting no closer relationship to Asia than to North America. Among the circumboreal species, which constitute about 35% (included with the endemics), the great majority originated in the Pacific (Durham & MacNeil, 1967). *Astarte elliptica* (Brown) and *Astarte montaguii* (Dillwyn) are faunal elements of Atlantic origin which suggest that the Bering Strait was open during or prior to deposition of the Middleton Island strata. The pectinid fauna is of North Pacific origin, although it is most closely related to forms known in Japan; at most, about 5% of the fauna can be considered to show Asiatic zoogeographic affinities. Approximately 18% of the fauna suggests faunal relationships with western North America, and about 2% may be considered cosmopolitan. One species, *Chlamys islandica kanagae* MacNeil (2% of the fauna; included with the endemics) appears ancestral to a North Atlantic taxon.

SUMMARY and CONCLUSIONS

Tables 1 and 2 summarize data on the mollusk-bearing stratigraphic units discussed; Figure 2 also shows suggested correlations among them.

Analysis of these data permit several conclusions:

1. Neogene thermal histories of the western and northeastern Gulf of Alaska were distinctly different from each other (Addicott, 1969). The western Gulf had a climatic history similar to that of the conterminous

Table 1

Summary of data for some western Gulf of Alaska mollusk-bearing stratigraphic units. Because of dubious specific and generic identifications, the number of systematic entries on the faunal lists used for analysis differs from the number of taxa actually present. The number of taxa amenable to zoogeographic analysis is given in parentheses

Formation	Thickness	Age	Water depth	Temperature	Zoogeographic affinities (Figures very approximate)	No. of systematic entries (No. taxa analyzed)
Tugidak Formation	1500m	Beringian to Anvilian transgressions	upper outer neritic	cold	Asiatic: 5% North American: 10% Endemic: 83% (Circumboreal: 46%) Cosmopolitan: 1%	98 (78)
Tachilni Formation	61m +	Graysian ("Jacalitos" to "Etchegoin")	shallow subtidal to inner neritic	cool temperate	Asiatic: 16% North American: 21% Endemic: 63% (Pre-circumboreal: 26%)	20 (19)
Upper Unnamed Member of the Bear Lake Formation	1525m to possibly 3000m(?)	Wishkahan	shallow subtidal to inner neritic	warm temperate	Asiatic: 21% North American: 48% Endemic: 31% (Pre-circumboreal: 10%)	48 (29)
Unga Conglomerate Member of the Bear Lake Formation	244m	late Newportian to early Wishkahan	subaerial to upper outer neritic	warm temperate	Asiatic: 35% North American: 24% Endemic: 41%	25 (17)
Narrow Cape Formation	700m	Newportian	shallow subtidal to outer neritic	warm temperate, perhaps near outer tropical boundary	Asiatic: 33% North American: 53% Endemic: 13% (Pre-circumboreal: 3%)	45 [Fauna includes about 80 taxa, however] (30)
Narrow Cape Formation of Sitkinak Island	210m	Juanian	outer neritic	near cool temperate-mild temperate boundary	Asiatic: 32% North American: 35% Endemic: 30% (Pre-circumboreal: 14%) Cosmopolitan: 3%	57 (37)

western United States. In contrast, Miocene temperatures of the northeastern Gulf were cooler and appear to be related to local glaciation which began about 20 million years ago (PLAFKER & ADDICOTT, 1976).

2. Sea surface temperatures in the northeast Gulf were as warm as the mild temperate zone when glaciation began; temperatures cooler than the present cool temperate conditions were not reached before late Pliocene (Beringian) time. The thermal history proposed here differs significantly from those of BANDY *et al.* (1969) and KANNO (1971) who inferred cold-water (Arctic) conditions throughout Yakataga time.
3. Asiatic faunal affinities are generally greater in the western Gulf area than in the northeastern area; both show significant declines during Miocene time.
4. North American faunal affinities are most pronounced during periods of relatively warm water conditions as represented by the faunas of the Poul Creek, Narrow Cape, and upper Bear Lake Formations. Substantially fewer taxa with North American affinities are recorded in the faunas of the Yakataga, Tachilni, and Tugidak Formations; these decreases are correlated with cooler water temperatures and increased provincialism and faunal endemism.

Table 2

Summary of data for some northeastern Gulf of Alaska mollusk-bearing stratigraphic units. Because of dubious specific and generic identifications, the number of systematic entries on the faunal lists used for analysis differs from the number of taxa actually present. The number of taxa amenable to zoogeographic analysis is given in parentheses.

Northeastern Gulf of Alaska

Formation	Thickness	Age	Water depth		Temperature	Zoogeographic affinities (Figures very approximate)	No. of systematic entries (No. taxa analyzed)	
Yakataga Formation at Middleton Island	1181 m	Anvilian transgression	lower inner neritic to upper outer neritic; occasionally shallower		cold	Asiatic: 5% North American: 18% Endemic: 75% (Circumboreal: 35%) (Pre-circumboreal: 2%) Cosmopolitan: 2%	115 (60)	
Yakataga Formation (Mainland, Kayak and Wingham Islands)	$\sim$5000 m including Middle-ton Is. beds	Anvilian? transgression at top (Chaix Hills)	deeper to southwest; shallower to north and east	intertidal and shallow subtidal to inner neritic in upper part	cold at top? cool temperate in upper part	Asiatic: 10% North American: 26% Endemic: 62% (Pre-circumboreal and Circumboreal: 26%) Cosmopolitan: 3%	42 (39)	121 (104)
		Newportian at base at Yakataga Reef		lower inner neritic to outer nerit-ic at Yaka-taga Reef	near mild tem-perate-cool temperate boundary at Yakatage Reef	Asiatic: 12% North American: 28% Endemic: 58% (Pre-circumboreal: 12%) Cosmopolitan: 2%	48 (43)	
		Juanian? and Pillarian at base on Kayak Island		upper bathyal at base on Kayak Is.	mild temperate at base on Kayak Island	Asiatic: 41% North American: 14% Endemic: 45% (Pre-circumboreal: 9%)	31 (22)	
Poul Creek Formation	1859m	*Echinophoria dalli* zone (upper Galvinian) to Pillarian	lower inner neritic to outer neritic		mild temperate at top – – – – – – warm temperate	Asiatic: 18% North American: 52% Endemic: 30% (Pre-circumboreal: 6%)	107 (87)	

5. In general, species that are locally endemic or endemic to the high latitude perimeter of the North Pacific are more abundant in the northeast Gulf of Alaska area. Faunal endemism is at a minimum during warm-water conditions.
6. Some taxa appeared in the Gulf of Alaska prior to the late Pliocene (Beringian) opening of the Bering Strait, and later achieved circumboreal distributions or gave rise to taxa that did. These "pre-circumboreal" taxa are therefore a special category of North Pacific endemic species. The earliest of these taxa appear in Juanian (late Oligocene) strata of the Gulf. They increase upsection in cool-water units, but decrease during warm-water conditions.
7. Endemic (includes "pre-circumboreal" and circumboreal) taxa increase upsection in the Yakataga Formation to a maximum of 75% of the Middleton Island fauna. This group increases upsection in the western Gulf to 83% in the Tugidak Formation. These data underscore the difficulty in correlating the late Neogene and Quaternary molluscan faunas of the Gulf with conterminous western United States faunas.

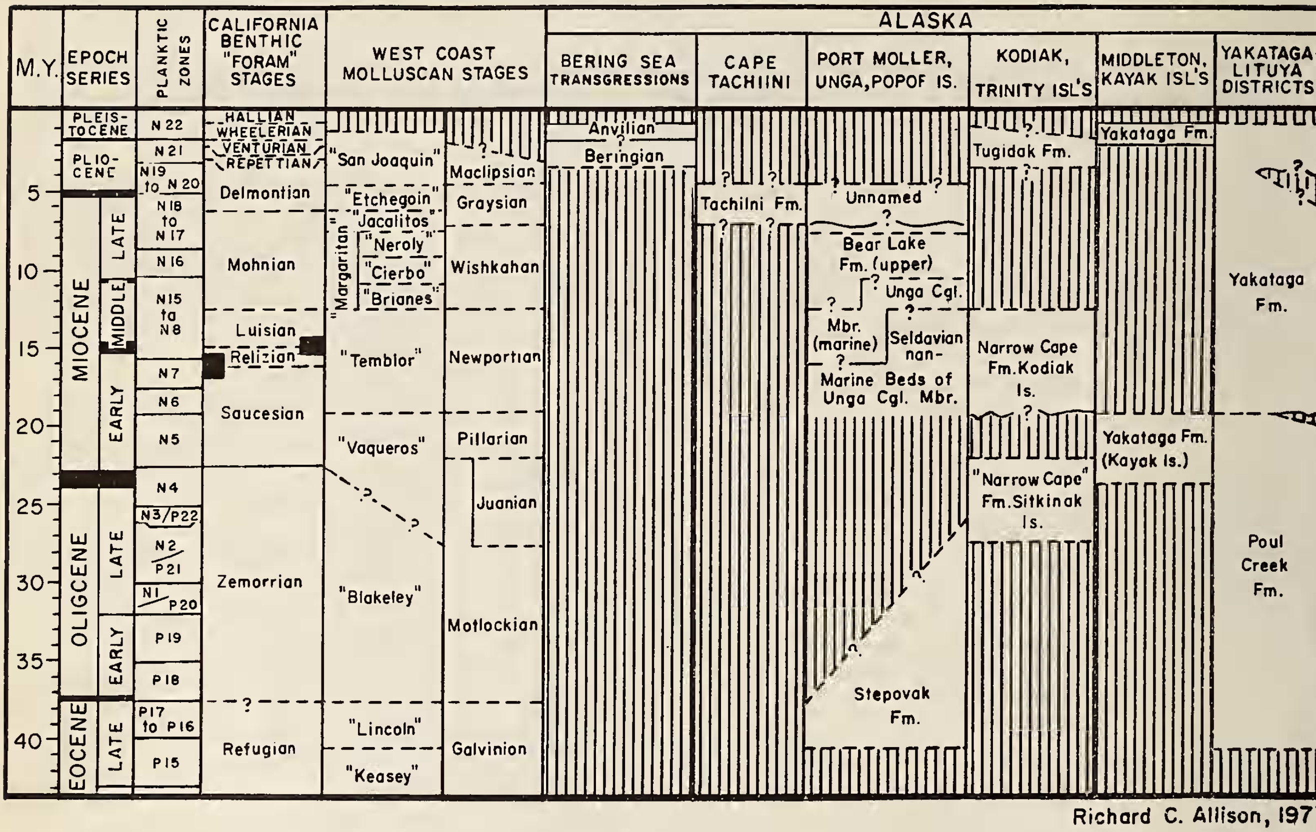

Figure 2

Tentative correlations of major late Paleogene to Pleistocene mollusk-bearing stratigraphic units of the Gulf of Alaska Region. Radiometric time-scale, epochs, planktonic zones, and California benthic foraminifer stages adapted from Berggren & van Couvering (1974: figs. 1 and 15) and modified by reference to Everenden *et. al.* (1964), Lipps (1967), Turner (1970), Berggren (1972), Hornaday (1972), Lipps & Kalisky (1972), Stainforth *et al.* (1975), and Howell (1976). The California benthic chronology is, however, tied to the planktonic zones and radiometric time-scale by relatively few control points. Several authors (*e.g.*, Ingle, 1967; Bandy, 1972; and Pierce, 1972) have suggested that some California benthic foraminifer stage boundaries may be time-transgressive, thereby further complicating correlations.

The West Coast molluscan stage chronologies are adapted from Weaver *et al.* (1944), Durham *et al.* (1954), Adegoke (1969), Addicott (1972), Armentrout (1975), and Addicott (1976). The molluscan stages are somewhat loosely tied to the benthic foraminifer stages and to the North American land-mammal ages for which some radiometric dates are available (Everenden *et al.*, 1964, and Savage, 1972).

The Alaskan molluscan faunas have been correlated with the West Coast molluscan chronologies and the Bering Sea transgression cycles (Hopkins, 1967). Vertical ruling indicates either hiatus, or absence of major mollusk-bearing stratigraphic units. Thick black lines at the sides of some chronostratigraphic boundaries indicate the probable range of accuracy of the boundary position as determined by radiometric dating.

8. Analysis of the biogeographic affinities of the faunas suggests that the first exchange of North Pacific and North Atlantic taxa through the Bering Strait may have been during the late Miocene, perhaps at the beginning of Wishkahan time some 10 to 13 million years ago (Hopkins, 1967b: 454). The later Beringian (late Pliocene) opening of the Bering Strait permitted many North Pacific taxa to migrate into the North Atlantic (Hopkins, *loc. cit.*) and allowed a lesser number of North Atlantic and boreal species

to reach the Bering Sea and North Pacific (DURHAM & MACNEIL, 1967).

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